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14. ABSTRACT
The DURIP program "Variable-temperature Microwave Impedance Microscope with Light Stimulation for Research on Photo-induced Phase Transitions" supported by ARO has been successfully completed. This novel apparatus will be the first scientific instrument that offers mesoscopic conductivity information with laser excitation under variable temperatures from 10 to 300 K. The innovative experimental investigations enabled by this system includes (1) Nanoscale coexisting phases in chalcogenide glasses; (2) Light-driven versus temperature-driven phase

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Report Title

Final Report: Variable-temperature Microwave Impedance Microscope with Light Stimulation for Research on Photo-induced Phase Transitions

ABSTRACT

The DURIP program "Variable-temperature Microwave Impedance Microscope with Light Stimulation for Research on Photo-induced Phase Transitions" supported by ARO has been successfully completed. This novel apparatus will be the first scientific instrument that offers mesoscopic conductivity information with laser excitation under variable temperatures from 10 to 300 K. The innovative experimental investigations enabled by this system includes (1) Nanoscale coexisting phases in chalcogenide glasses; (2) Light-driven versus temperature-driven phase separation in transition metal oxides; (3) Spatial distribution of photo-induced hidden states associated with charge-density waves. The research to be conducted based on this platform will provide significant amount of new knowledge on many advanced materials that are important for military applications in photo sensing and data storage.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

“Noninvasive Conductivity Imaging of 2D Materials and Devices by Microwave Impedance Microscopy”, 2016 IEEE MTT-S International Microwave Symposium (IMS), May 2016, San Francisco, CA.

Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received	Paper

TOTAL:

Number of Manuscripts:

Books

Received	Book

TOTAL:

Received   Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Keji Lai, Presidential Early Career Awards for Scientists and Engineers (PECASE), 2016

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

Final Report: Variable-temperature Microwave Impedance Microscope with Light Stimulation for Research on Photo-induced Phase Transitions

Defense University Research Instrumentation Program (DURIP)

Army Research Office Grant # W911NF-16-1-0276

PI: Keji Lai, University of Texas at Austin, Department of Physics, Austin, TX 78712

List of illustrations:

Statement of the Problem

The objective of this DURIP award is to develop a variable-temperature microwave impedance microscope (MIM) [1, 2] with intense laser illumination for the research of photo-induced phase transitions (PIPTs). Different from the thermally driven phase transitions (Fig. 1a), a PIPT is initiated by the photo-excited carriers that redirect the system to a new stable or metastable phase [3 – 5], as illustrated in Fig. 1b. Owing to the intricate interplay among disorders, electron-electron interactions, and competing orders, electronic inhomogeneity with different spatial configurations (Fig. 1c) is ubiquitously observed in semiconductors, complex oxides and other functional materials [6, 7]. Before our work, however, mesoscopic phase separation has not been addressed for the PIPTs observed in advanced materials. It is our goal to combine the MIM with nanoscale imaging capability and laser excitation to study the microscopic details of these processes.

Thanks to the ARO-DURIP support, we have acquired all components of the targeted setup, including an optical table, a cryogenic chamber, stepping/scanning stages and control electronics, a customized set of microwave electronics, and a set of laser optics for the light stimulation. The system will be soon completed in the PI's laboratory. MIM is a powerful technique to spatially resolve the mesoscopic (10 ~ 100 nm) electrical properties without the need of contact electrodes [1, 2]. This novel apparatus will be the first scientific instrument that offers mesoscopic conductivity information with CW or pulsed laser excitations under variable temperatures (10 – 300 K). The research to be conducted based on this platform will provide significant amount of new knowledge on many advanced materials that are important for military applications in photo sensing and data storage.

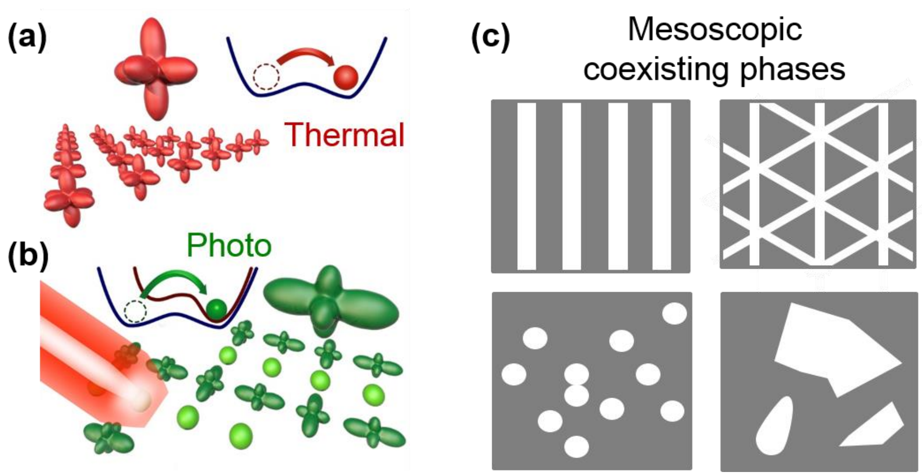

Fig. 1. (a) Schematic of the conventional phase transition driven by thermal fluctuations, where the new phase occurs spontaneously. (b) Schematic of the photo-induced phase transition in complex systems [8], where the system is redirected to a stable or metastable by photo-generated carriers. (c) Schematics of mesoscopic coexisting phases with different spatial configurations.

Summary of Key Results

Fig. 2a illustrates the configuration of the cryogenic light-assisted MIM setup. A photo of the system currently under construction is shown in Fig. 2b. Specifically, we have acquired the following components for the proposed experiments.

a. An optical table from Technical Manufacturing Corporation, on which the cryostat and optical parts are mounted.

b. A microscopy cryostat from Janis Research Company modified to host the MIM.

c. A set of variable-temperature scanning/positioning stages and control electronics from AttoCube Systems.

d. A set of customized MIM electronics.

e. Continuous-wave (CW) and pulsed 510-nm laser source from Market Tech Inc. and the peripheral optics (objective, mirrors, lenses, and manual positioning stages).

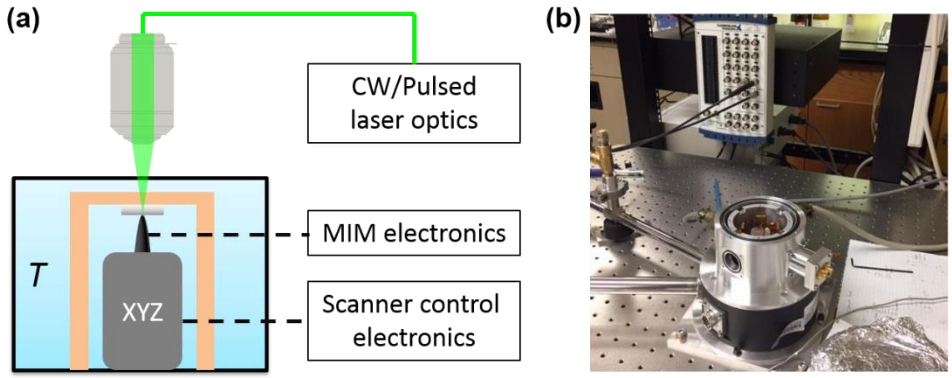

Fig. 2. (a) Schematic of the low-temperature MIM system with CW/pulsed laser stimulation. (b) Photo of the system currently under final construction and testing.

A section of the PI's lab is being renovated to meet the standard requirement of Class 3B laser for this system. The MIM electronics, scanning/positioning stages, and the scan control software have all been tested. We expect that the complete system will be up and running by the beginning of Fall, 2017. A number of innovative experimental investigations enabled by this instrument in the near future (1 ~ 3 years) include:

- Nanoscale coexisting phases in chalcogenide glasses. The new instrument will allow us to study the microscopic origin of PIPTs in these materials, which are attractive for rewritable data storage and photo-sensing applications [9].

- Light-driven versus temperature-driven phase separation in transition metal oxides. If the sizes, shapes, and dynamics of the competing metallic and insulating states differ drastically in the two experiments, the result may imply very different physical mechanisms [8, 10, 11].

- Spatial distribution of photo-induced hidden states associated with charge-density waves. By tracing the formation and melting processes in the real space, we expect to shed some light on the dynamics and possible phase competition in these materials [12].

To summarize, thanks to the DURIP support, the PI's group has acquired the necessary parts to construct a new tool for probing light-driven phenomena in novel quantum materials at the nanoscale. The work will establish a new research direction and augment existing DoD programs at UT-Austin. The research is of fundamental importance for Army applications of photosensitive materials in future sensing and data storage devices.

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